Effect of Constant Curvature Vane Tip on RF Quadrupole Linac Beam Dynamics (Commemoration Issue Dedicated to Professor Hidekuni Takekoshi On the Occasion of His Retirement)

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The authors calculated the multipole field coefficients of the general RFQ potential by using boundary element method (BEM). The beam dynamics of the RFQ of Kyoto University was simulated by the computer code with the new accelerating field strength evaluated from BEM. The results were compared with those obtained from the simulation in which the two-term potential is assumed for the RFQ field.

KEY WORDS: RFQ linac/ Constant curvature vane tip/

1. INTRODUCTION

RFQ linacs can accelerate DC beams directly from an ion source, bunching them simultaneously. At the Facility of Nuclear Science Research, Institute for Chemical Research, Kyoto University, a 7-MeV proton linear accelerator is now being tested[1]. This linac is composed of a 2-MeV RFQ linac and an Alvarez drift tube linac.

In the simulation code PARMTEQ[2], the simple form of the RFQ potential, which is called the two-term potential, is assumed:

$$U=\frac{V}{2}\left[\left(\frac{r}{r_0}\right)^2 \cos 2\theta+AI_0(kr)\cos kz\right] \tag{1}$$

$$A=\frac{m^2-1}{m^2I_0(ka)+I_0(mka)} \tag{2}$$

where A is an accelerating efficiency, m is a modulation parameter, a is the minimum bore radius, r_0 is the mean bore radius, V is the intervane voltage and $k=\pi/L_c$ where L_c is a cell length. The vane geometry necessary to achieve the two-term potential field is

$$\left(\frac{r}{r_0}\right)^2 \cos 2\theta+AI_0(kr)\cos kz=1 \tag{3}$$

However, the actual potential of the RFQ linac of Kyoto Univ. is different from the two term potential, because the cross section of the vane tip has the constant curvature.

In this paper, we present the results obtained by a program in which 3-D BEM is used to calculate the multipole coefficients of the general RFQ potential and the effect of the constant curvature vane tip on the RFQ potential is discussed. Using the results of BEM, the beam dynamics of the RFQ is also studied.

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2. PROGRAM

To calculate the RFQ general potential, we solve the Laplace equation in each unit cell. For BEM calculation, let us express the Laplace equation as

$$\phi+\int_s \phi \frac{\partial \varphi}{\partial n} dS=\int_s \varphi \frac{\partial \varphi}{\partial n} dS \tag{4}$$

where ϕ is the potential function of a specified cell, S is the surface of the vane tip and $\varphi=(4\pi r)^{-1}$. Eq. (4) can be transformed into a matrix formulation by subdividing the boundary into meshes. The LU expansion method was used to solve the matrix equation. We used a VAX station for the calculation.

The general RFQ potential is given as

$$U=\frac{V}{2}\left[\sum_{n=1}^{\infty} A_{0m}\left(\frac{r}{r_0}\right)^{2m}\cos 2m\theta+\sum_{n=1}^{\infty}\sum_{m=0}^{\infty} A_{nm} I_{2m}(nkr)\cos 2m\theta \cos nkz\right] \tag{5}$$

where the summation in eq. (5) must be performed under the condition that cos (mp)× cos (np)$=-1$. We calculated the coefficients of four lowest order terms, i. e. A_{01}, A_{10}, A_{03} and A_{12}.

3. DISCUSSIONS

Table 1 shows the multipole coefficients and intervane capacitances evaluated from the BEM calculations with the design parameters of the specified cells of our RFQ linac. Figs. 1 (a), (b) and (c) show the values of A_{01}, A_{10}/A and intervane capacitance respectively corresponding to the various values of cell length and modulation parameter. As is clear from Fig. 1 (b), the value of A_{10} is rather different from the one expected in the PARMTEQ code.

Fig. 2 shows transmission efficiency as a function of input current. Two curves

Table. 1. Cell parameters and multipole coefficients of the specified cells of our RFQ.

Cell number	a	m	CL	A_{01}	A_{10}/A	A_{03}	A_{12}	Capacitance (pF/m)
20	0.299	1.007	0.357	0.983	0.586	0.031	0.004	27.69
60	0.292	1.056	0.359	0.978	0.749	0.061	0.079	27.82
100	0.288	1.087	0.373	0.977	0.770	0.051	0.125	27.78
150	0.288	1.090	0.414	0.976	0.788	0.048	0.118	27.67
200	0.282	1.117	0.515	0.977	0.848	0.062	0.141	27.67
230	0.279	1.155	0.647	0.972	0.873	0.033	0.085	27.61
250	0.270	1.227	0.797	0.979	0.913	0.038	0.095	27.57
275	0.202	1.900	1.260	1.010	0.984	0.087	0.066	28.08
300	0.200	1.900	1.851	1.016	1.012	0.195	0.155	28.27

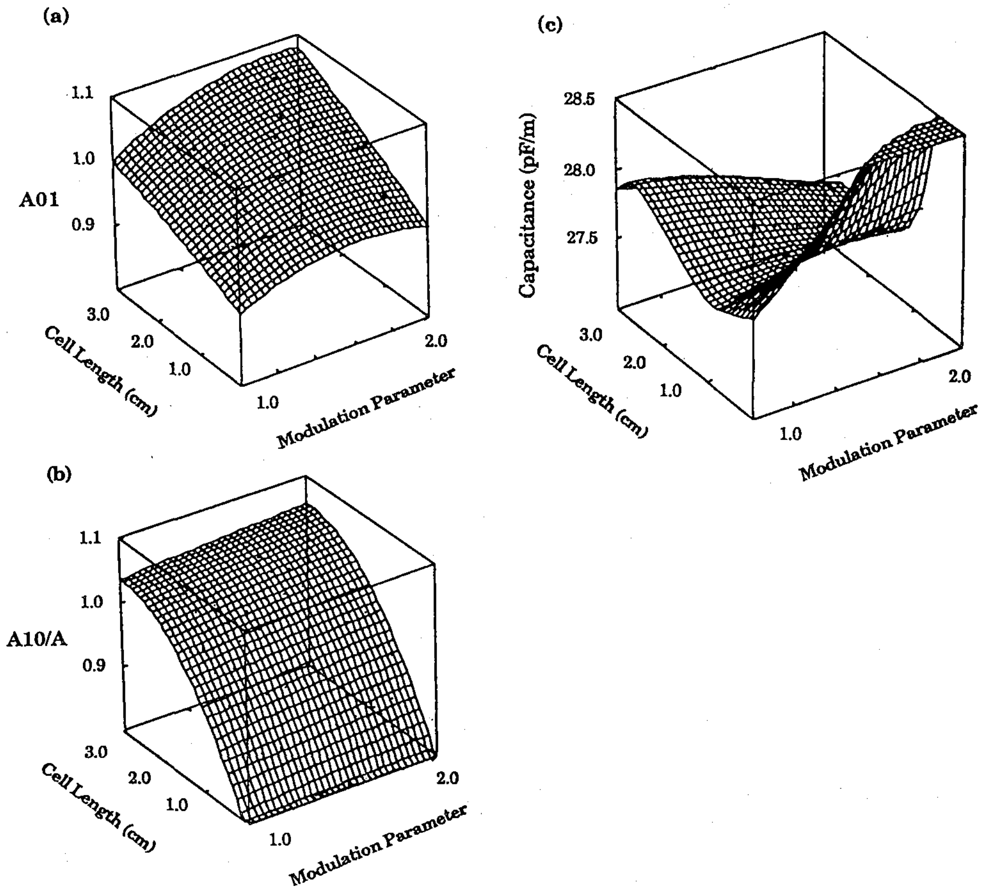

Fig. 1. Variation of multipole coefficients and intervane capacitance as a function of cell length and modulation parameter.
(a) A_{01}.
(b) The ratio of A_{10} to the accelerating coefficient A.
(c) Intervane capacitance.

in this figure correspond to the two cases below;

case 1: PARMTEQ simulation results with the two-term potential

case 2: PARMTEQ simulation results with the general potential

In these simulations, the design parameters of our RFQ were used. It is shown in Fig. 2 that the transmission efficiency of case 2 is a few percents smaller than that of case 1 when input current is below 50 mA.

There are two possible methods to make sure the design transmission efficiency. The one is to increase the intervane voltage in the entrance region of the RFQ, the other is to change the modulation parameter and minimum bore radius to compensate the decrease of A_{10}. Fig. 3 shows the design modulation parameter of our machine and the corrected modulation parameter to achieve the design transmission. Fig. 4 shows the design intervane voltage of our machine and the linearly tilted intervane voltage to achieve the design transmission. By means of these procedures, we can make sure the design transmission efficiency obtained by PARMTEQ simulation with

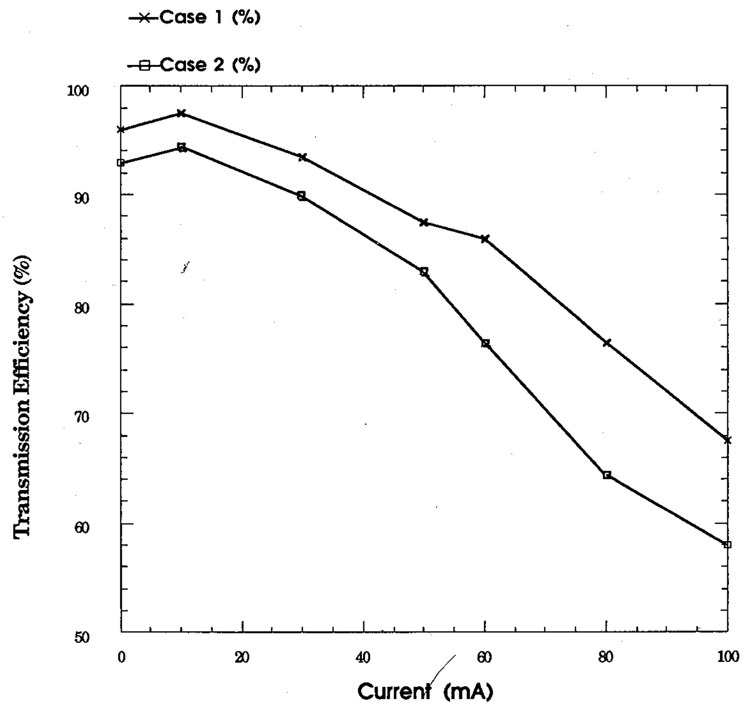

Fig. 2. Variation of transmission efficiency v. s. input current.

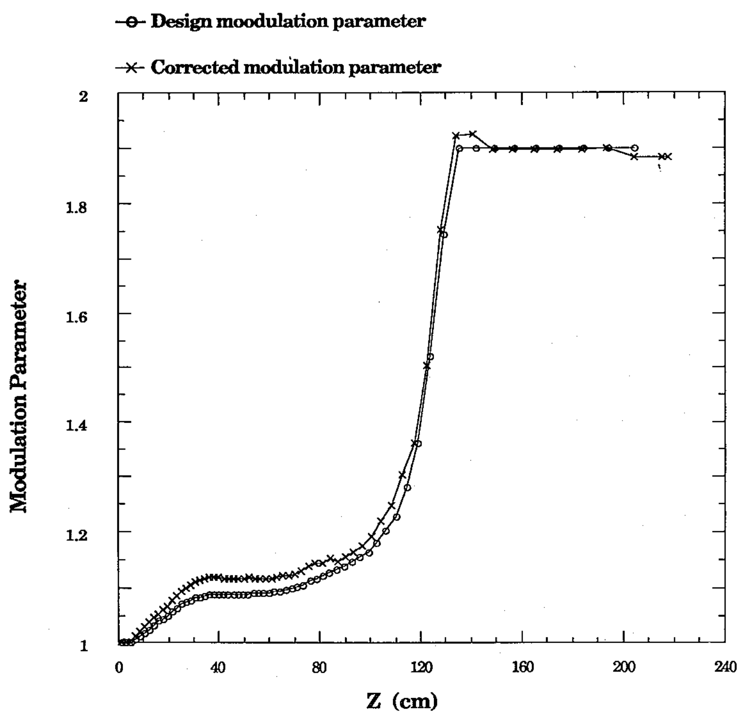

Fig. 3. Variations of the design modulation parameter and corrected one along the structure.

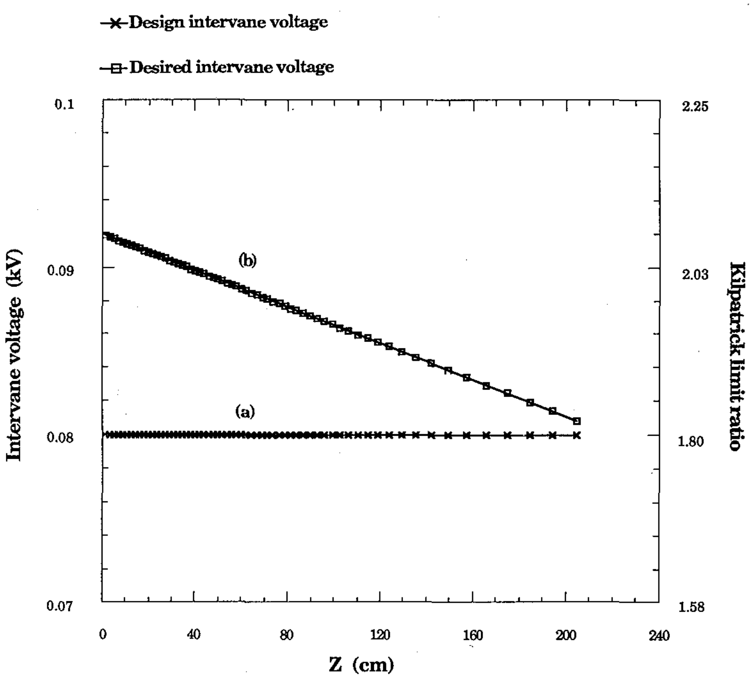

Fig. 4. Intervane voltage v. s. longitudinal coordinate.
(a) The design voltage.
(b) A desired voltage for our RFQ to achieve the design transmission.

the two-term potential.

4. CONCLUDING REMARKS

When we use the constant curvature vane tip, the value of the coefficient A_{10} becomes smaller than that expected in the usual PARMTEQ simulation in which the two term potential is assumed. This fact affects the beam dynamics, resulting in the reduction of the transmission efficiency.

To compensate the reduction of design efficiency due to the constant curvature vane tip, we may make the adequate correction to design modulation parameter obtained in the usual PARMTEQ simulation. As for our RFQ linac, to which no such correction is made, it will be necessary for the design transmission that the intervane voltage distribution should not be tuned flat but tilted to the amount of 15% as shown in Fig. 4.

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